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1/77

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P021570GB

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0216331.9

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4500 Dorr Street  
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USAPatents ADP number (*if you know it*)

51649002

If the applicant is a corporate body, give the country/state of its incorporation

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4. Title of the invention

Bearings

5. Name of your agent (*if you have one*)

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**DUPLICATE**

P021570GB

**BEARINGS**

5....The present invention relates to plain journal bearings, particularly though not exclusively, for internal combustion engines and to so-called overlay coatings deposited upon the running sliding surface of such bearings.

10

Overlay coatings on plain journal bearings are well known. Such coatings are used to improve the running characteristics of plain bearings. Generally, overlay coatings are relatively soft metal alloys having a 15 hardness in the region of about 15Hv; are frequently based on alloys of lead; and, are deposited on another harder bearing alloy at a thickness in the range from about 10 to 30 $\mu$ m. Overlay alloys of the type under consideration are usually applied by electro-deposition 20 from aqueous plating solutions.

The bearings on which the overlays are deposited are of generally cylindrical or, more commonly, semi-cylindrical form as half-bearing shells which support the crankshaft 25 journals of internal combustion engines, for example. Such bearings generally comprise a layer of a strong backing material such as steel, for example, on which is a layer of a bearing material frequently chosen from alloys of aluminium or copper. The method of attaching 30 the layer of bearing alloy to the strong backing may be any that is suitable and may include techniques such as pressure welding of sheets of bearing alloy to the backing; the casting of molten alloy onto the backing; or, the sintering of powders of alloy to the backing, for

example, these methods not being exhaustive. The overlay alloy coating is deposited on the surface of the harder bearing alloy and endows the finished bearing so formed with properties which include conformability and the  
5 ability to embed dirt particles and so prevent scoring of a shaft journal by particles of debris carried in the lubricating oil. Although overlay alloys in their bulk form are relatively weak alloys, they have the ability when applied as a thin layer to another, harder bearing  
10 alloy to increase the fatigue strength of a bearing embodying that harder and intrinsically stronger bearing alloy. This is effected due to the conformability of the overlay alloy by being able to deform slightly to accommodate slight mis-alignments, especially in new  
15 engines during the "running in" phase, and so spread the load more evenly across the bearing surface area.

As noted above, many conventional overlay alloys are based on alloys of lead. Lead is a toxic metal which will  
20 eventually be phased out of use by governmental legislation throughout the world. In order to make the lead overlay layer less prone to corrosion in hot engine oils about 10 weight% of tin is frequently added or, alternatively, 7 to 10 wt% of indium. Indium, however, is  
25 relatively very expensive compared with tin and tends to be used for more expensive, higher performance vehicles. However, when tin is used in the overlay alloy and is deposited upon a harder bearing alloy such as copper-lead, for example, a problem exists in that the tin under  
30 engine operating conditions tends to diffuse out of the overlay into the lead of the underlying bearing alloy, as does indium. This is solved by coating the surface of the underlying, harder bearing alloy with a thin diffusion barrier of about  $1\text{-}3\mu\text{m}$  of a metal such as nickel.

However, this is not entirely satisfactory as diffusion still occurs and the overlay still becomes depleted in tin due to the formation of non-equilibrium intermetallic compounds such as  $\text{Ni}_3\text{Sn}$  or  $\text{Ni}_3\text{Sn}_2$ , which are not good bearing materials in the situation where the shaft journal wears through the overlay to the underlying interface comprising these intermetallic compounds.

- With the ever increasing demands placed on bearings by engines having higher specific outputs and operating at higher engine revolutions, there has been a demand for these relatively soft overlay alloys to have improved wear resistance whilst at least maintaining existing levels of fatigue, cavitation and corrosion resistance.
- This demand has resulted in the development of so-called lead-tin-copper overlay alloys an example of which is Pb-10Sn-2Cu.

Thus, it is an object of the present invention to provide an overlay layer which is not toxic and a further object to provide an overlay which does not form undesirable compounds at an interface with an underlying, harder bearing material. A yet further object is to provide an overlay having improved performance over known lead-based overlay alloys.

According to a first aspect of the present invention there is provided a plain bearing having an overlay material layer at a sliding surface of the plain bearing, the plain bearing comprising a layer of a strong backing material, a layer of a first bearing alloy bonded to the strong backing material and a layer of a second bearing alloy comprising said overlay material bonded to said first bearing alloy layer wherein said second bearing

material comprises tin having included in the matrix thereof an organic levelling agent.

The tin overlay layer according to the present invention  
5 comprises essentially pure tin in that there are no metallic alloying constituents, other than unavoidable impurities, however, the tin is deposited from a bath containing additions of one or more organic materials which have the effect of so-called "levelling" on the  
10 electro-deposited tin layer.

Organic materials which have been tested in bearings of the present invention embodying tin overlays include nonylphenolpolyglycoether and pyrocatechol. The content  
15 of the organic material in the plating bath has an influence on the degree of levelling achieved in the deposited tin layer, the degree of levelling being reflected in the surface roughness of the tin layer.

20 At low levels of organic levelling agent, too low for the full benefit of the present invention to be felt, the surface appearance of the bearing surface is one of a general crystalline appearance having pools of smooth material distributed over the surface. At a content of  
25 organic levelling agent where the whole surface is smooth, this is the desirable minimum content.

It is believed that the organic levelling agent is incorporated in the matrix of the deposited tin layer as  
30 polymer chains occluded in the matrix structure such as in the form of an organo-metallic tin compound, for example. The polymer chains appear to impart a preferred orientation to the tin atoms during deposition which has been found to give improved slip properties. Improved  
35 slip properties have been evidenced by lower coefficients

of friction in the tin layer compared with ordinary tin deposits without the levelling additions. The surface of the tin overlay of the bearing of the present invention is very smooth giving a lower degree of friction against

5 a co-operating shaft journal which in turn gives improved compatibility between bearing surface and shaft journal resulting in lower wear rates.

The organic constituent of the tin overlay produces an

10 increased hardness in the range from about 20 to 30Hv. Pure tin with no organic levelling agent, depending upon its condition, has a hardness of about 8-12Hv. The hardness of the tin overlay can be changed depending upon the content of the organic levelling agent in the plating

15 bath; the lower the content, the lower the corresponding hardness. The reverse is also true in that as the content of levelling agent increases, so also does the hardness. However, it is possible to have too high a content of organic levelling agent such that the hardness is too

20 high and high internal stresses are produced in the deposit which can lead to cracking of the tin deposit. It is intended that the overlay of the bearing of the present invention operates in a similar manner to conventional overlays in that the overlay layer is

25 sufficiently soft to permit particles of dirt circulating in the lubricating oil to become embedded in the overlay so as to prevent such dirt particles from scoring the shaft journal. Whilst the tin overlay of the present invention is harder than pure tin by a factor of X2 to X3

30 it is still sufficiently soft to provide the required characteristic of dirt embeddability thus, the preferred hardness range is 20 to 30Hv.

The bearing of the present invention may preferably have

35 an interlayer between the surface of the first bearing

material and the tin overlay to act as a diffusion barrier therebetween. The metal layer may be of a thickness lying in the range from about 0.1 to about 3 $\mu$ m with a thickness of 1 to 2 $\mu$ m being commonly used,

5 however, the actual thickness is of comparatively little importance in terms of bearing performance. The metal may be selected from the non-exhaustive group including nickel, cobalt, copper, silver, iron and alloys of these metals, for example. It has been found that under engine

10 operating conditions the tin overlay reacts with the interlayer over time to form the stable equilibrium intermetallic compound, Ni<sub>3</sub>Sn<sub>4</sub>, due to the presence of effectively an excess of tin. As noted above, prior art lead-tin overlays tended to form the unstable, non-

15 equilibrium Ni<sub>3</sub>Sn or Ni<sub>3</sub>Sn<sub>2</sub> compounds which are poor bearing materials and have inferior compatibility with a shaft journal and have been blamed in the past for causing seizure when the overlay has worn through to the interlayer. Ni<sub>3</sub>Sn<sub>4</sub> on the other hand is a very good

20 bearing material and thus, the overlay of the present invention in addition to having superior resistance to wear and cavitation erosion is also less prone to seizure when the overlay is nearing the end of its life. Thus, this unforeseen effect of generating a good bearing

25 material at the interface is seen as a significant advantage of the bearing of the present invention.

As with known overlay layers, the thickness of the overlay of the bearing of the present invention may lie

30 in the range from about 10 to 30 $\mu$ m with 13 to 18 $\mu$ m being preferred.

The deposition conditions for tin overlays according to the present invention may be varied to produce a range of

microstructures. For example, analysis of the tin overlay layer by SEM has revealed no discernible grain size; even at magnifications of X5000 and X10000 no grains can be resolved. However, coatings having grain sizes of up to 5  $3\mu\text{m}$  may be produced. It is preferred, however, that a smaller grain size is produced as these provide improved bearing properties.

According to a second aspect of the present invention, 10 there is provided a method for the deposition of an overlay layer onto the surface of a plain bearing, the bearing comprising a strong backing material having a layer of a first bearing material thereon, said overlay being deposited upon the surface of said first bearing 15 material, the method comprising the steps of: providing a bearing having a surface on which to deposit said overlay; immersing said bearing in a plating solution having a supply of tin ions and an organic levelling agent in said solution; making said bearing cathodic with 20 respect to an anode in said solution; and depositing an overlay of tin, apart from unavoidable impurities, said tin overlay also having said organic levelling agent included in a matrix thereof.

25 It is preferred to deposit the tin overlay of the bearing of the present invention by using a so-called "slot jig" wherein the bearing is held with its joint faces against a back face of the slot jig with the bore of the bearing facing the slot, the bearing axis and slot 30 being generally parallel to each other. The plating solution, in which the bearing and slot jig are immersed, is also then sparged through the slot towards the bearing bore. In this way it has been found that relatively high current densities of 2 to  $3\text{ A/dm}^2$  may be employed

- compared with less than 1 A/dm<sup>2</sup> where the bearing is merely immersed in the plating solution without sparging thereof. Furthermore, the quality of the deposited tin layer is greatly improved compared with that produced
5. without sparging. The use of high current density permitted by the slot jig and sparging technique also reduces plating time from more than 40 minutes to less than 20 minutes.
- 10 A typical plating solution producing a tin/organic material overlay on a bearing according to the present invention may have a composition as follows:

	Sn <sup>++</sup>	32-38 g/l
15	SnSO <sub>4</sub>	58-68 g/l
	H <sub>2</sub> SO <sub>4</sub>	185-210 g/l
	Cu	<50mg/l
	Chloride	<20ppm

- 20 Levelling agent additions of nonylphenolpolyglycolether (10-25%) in a methanol carrier (2.5-10%) in the range from 18 to 70 ml/l to the solution specified above have been tested. At the lower end of the range it was found that the degree of levelling and hardness increase was
- 25 insufficient whilst at the upper end of the range it was found that there was too much inherent stress in the tin deposit and cracking occurred. It was found that concentration in the range from 25 to 55ml/l gave useful increases in overlay performance with little or
- 30 acceptable deterioration of the fundamental requirements of an overlay alloy in terms of conformability and dirt embeddability. The content of pyrocatecol was 2.5-10% and amphoteres tensid 2.5% maximum.

It has been found that the leveller content has a substantially directly proportional effect on hardness of the tin deposit. However, a limit of leveller content is reached after which the hardness of the tin deposit  
5 remains constant and then actually begins to fall after further increasing the leveller content. Similarly, the leveller content also has a directly proportional effect on surface roughness once the effect of the initial substrate roughness and greatly increased surface  
10 roughness of the initial leveller-free tin deposit have been overcome.

In order that the present invention may be more fully understood, examples will now be described by way of  
15 illustration only with reference to the accompanying figures, of which:

Figure 1 shows a cross section through a part of a schematic bearing according to the present invention  
20 showing the constituent layers;

Figure 2 shows a top view of a schematic arrangement of a plating jig having a bearing being plated with a tin/organic material according to the method of the  
25 present invention;

Figure 3 shows a histogram of mean thickness loss of overlay vs main journal number in an engine test comparing bearings according to the present invention and  
30 bearings plated with known Pb/In overlays;

Figure 4 shows a histogram of weight loss vs main journal number of overlays of bearings according to the present invention and known Pb/In plated bearings in a 3000hour  
35 engine test;

Figure 5 shows a histogram of volume loss of overlays of bearings according to the present invention and known Pb/In and Pb/Sn/Cu overlays in a hot oil corrosion test;

5

Figure 6 shows a histogram of fatigue strength of bearings according to the present invention having a tin/organic material overlay and known Pb/In and Pb/Sn/Cu overlays;

10

Figure 7 shows a histogram of volume loss of overlays of bearings according to the present invention, Pb/Sn/Cu and Pb/In overlays;

15

Figure 8 shows a graph of leveller content vs hardness; and

Figure 9 which shows a graph of leveller content vs surface roughness of the deposit on a substrate.

20

Referring now to Figure 1 which shows a cross section of a small portion of a generalised bearing 10 according to the present invention. The bearing comprises: a strong backing material 12 (only a part of the thickness of

25

which is shown); a layer of a first bearing material 14 bonded to the backing 12; an interlayer 16; and, an overlay layer 18 of tin which includes an organic levelling agent combined in the matrix thereof. The

backing layer 12 may be steel, for example, but may be

30

any other suitable material such as bronze for example if corrosion conditions in the application dictated such.

The first bearing material layer 14 may be any that is suitable but will generally be chosen from copper-based alloys or aluminium-based alloys. The interlayer 16 is

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present to form a diffusion barrier to stop rapid

diffusion of the tin from the overlay 18 into the bearing alloy layer 14 in the case of copper-based alloys 14 and to improve the adhesion of the overlay to the bearing alloy in the case of aluminium-based alloys 14. The interlayer will generally be deposited by electro-deposition where the overlay is so deposited and may comprise a layer of nickel or other suitable material as described hereinabove. In use, the bearing 10 will be subject to temperatures up to about 160°C. At temperatures of 90°C and above, the tin from the overlay will react with the interlayer material to form the stable intermetallic compound Ni<sub>3</sub>Sn<sub>4</sub> in the case of a nickel interlayer. The rate of formation increases as the temperature rises. The Ni<sub>3</sub>Sn<sub>4</sub> layer grows at the expense of the overlay, however, the Ni<sub>3</sub>Sn<sub>4</sub> layer is a good bearing material per se with good compatibility with the co-operating shaft journal (not shown) and thus, does not present a possible seizure threat. The thickness of the interlayer 16 generally lies in the range from 1 to 3µm and the thickness of the overlay 18 generally in the range from 13 to 18µm.

Figure 2 shows a top plan view of a schematic arrangement 20 of electro-plating apparatus for depositing an overlay 18 on a bearing 10. The apparatus comprises a jig 22 having two plates 24, 26 spaced either side of a slot 28. The bearing 10 is held against the plates 24, 26 on its joint faces 30. The jig 22 is immersed in a bath (not shown) of plating solution 32 as is a tin anode 34 of generally cylindrical form. The bearing 10 is made cathodic by a suitable electrical connection (not shown). A sparging tube 36 having holes 38 is situated vertically in the bath in a fixed relationship to the slot 28. Plating solution is pumped through the tube 36 so as to

emerge in jet form, as indicated by the arrows 40, which are directed towards the bore of the bearing 10 through the slot 28. Although not apparent from Figure 2, the jig 22 is elongate as are the anode 34 and sparging tube 36  
5 and there is generally a stack of a plurality of bearings 10 being plated simultaneously.

In the tests results which follow, the overlay was deposited upon the relevant substrate alloy bearing alloy 10 14 and interlayer 16 from a plating bath having the following composition:

	Sn <sup>++</sup>	32-38 g/l
	SnSO <sub>4</sub>	58-68 g/l
15	H <sub>2</sub> SO <sub>4</sub>	185-210 g/l
	Cu	<50mg/l
	Chloride	<20ppm

Levelling agent additions of nonylphenolpolyglycoether 20 (10-25%) in a methanol carrier (2.5-10%) in the range from 32 to 35 ml/l were added to the above aqueous solution.

The interlayer 16 material was in all case nickel.  
25

Figure 3 indicates the results of a 3000 hour test on a diesel truck engine. Main bearings 1 to 4 inclusive were fitted with bearings according to the present invention as described above whilst main bearings 5 to 7 inclusive 30 were fitted with bearings of the same material and construction but having a conventional overlay of Pb-7In. As may be seen from the histogram of Figure 3, the mean overlay thickness loss for bearings of the present

invention was less than 10% that of the conventional overlay.

Figure 4 shows the results of the 3000 hour Volvo engine test of Figure 3 in terms of weight loss. Weight loss of the bearings according to the present invention was significantly less than 100mg each for the four main bearings on journals 1 to 4 whereas the weight loss of the bearings on journals 5 to 7 was around 1000 mg each.

10

Figure 5 is a histogram showing weight loss of overlays in hot oil (white medicinal oil which is chosen for its particularly corrosive nature) after 1000 hours at 120°C, the loss being measured in  $\text{mm}^3$ . The bearing material on which the overlays were deposited has a composition CuSn10 which was cast onto steel. The overlays were tin as in the present invention, Pb-7In and Pb-10Sn-2Cu. As may be seen from Figure 5, the volume loss of overlays on bearings according to the present invention was about 60% that of Pb-10Sn-2Cu and much less than 10% that of the Pb-7In overlay.

Figure 6 is a histogram showing the fatigue strength of bearings having the overlays specified. The bearings according to the present invention were tested in two forms: one having a thickness of  $18\mu\text{m}$  at the upper end of the preferred thickness range; and, the second having a thickness of  $14\mu\text{m}$  at the lower end of the preferred thickness range. The overlay thicknesses of the prior art Pb-10Sn-2Cu and Pb-7In overlays was  $15-16\mu\text{m}$ . As may be seen from Figure 6 the fatigue strength of the bearings according to the present invention was significantly greater than the prior art bearings.

Further tests carried out where the tin overlay in a thickness in the range from 13 to 18 $\mu\text{m}$  was deposited on bearing materials 14 of Cu-30Pb-1.5Sn and Cu-10Sn gave fatigue strengths of 90 to 103 MPa.

5

Figure 7 is a histogram showing wear test results showing volume loss of overlay on bearings according to the present invention compared with conventional overlays as described hereinabove. The test conditions were:

10 temperature 120°; load 8kg; speed 500 rev/min; duration 10 mins; and a constant flow of 10W oil at 600ml/min. As may be seen from Figure 7 the volume loss of overlays according to the present invention is less than 50% of Pb-10Sn-2Cu and less than 40% that of Pb-7In.

15

Tests were also carried out on the cavitation resistance of overlays on bearings according to the present invention. In these tests, the weight loss of the tin overlay of the inventive bearing was 9mg whereas the

20 weight loss of a Pb-7In overlay under identical conditions was 37mg.

Figure 8 shows the effect of leveller content on the hardness of the tin deposit. It may be seen that the 25 hardness increases linearly with increasing content of leveller which was the same as that in the previously described example.

Figure 9 shows the effect of leveller content on surface 30 roughness of the tin deposit. At low leveller contents below about 2 ml/l of leveller, the high roughness is a consequence of the substrate surface roughness which was an Ra of 0.44 and the roughening effect of the initial, substantially leveller-free tin deposit. Once the effect

of the leveller was such that the surface roughness matched that of the substrate then increasing quantities of leveller were directly proportional to the surface roughness.

5

Thus, relatively low contents of leveller have a strong effect in hardening and smoothing out surface roughness of the tin overlays of the present invention.

10 Thus, it may be seen that the performance of overlays on bearings according to the present invention is greatly superior to the best conventional overlays deposited by electro-deposition. Where the overlay is deposited upon a lead-free bearing material 14, the bearing of the present  
15 invention provides a completely lead-free bearing which complies with future legislation relating to the elimination of lead from vehicles.

**CLAIMS**

1. A plain bearing having an overlay alloy layer at a sliding surface of the plain bearing, the plain bearing comprising a layer of a strong backing material, a layer of a first bearing alloy bonded to the strong backing material and a layer of a second bearing material comprising said overlay material bonded to said first bearing alloy layer wherein said second bearing material comprises tin having included in the matrix thereof an organic levelling agent.
2. A plain bearing according to claim 1 wherein the organic material is selected from at least one of: nonylphenolpolyglycolether and pyrocatechol.
3. A plain bearing according to either claim 1 or claim 2 wherein the hardness of the overlay is in the range from about 20 to 30Hv.
4. A plain bearing according to any one preceding claim further including an interlayer between the surface of the first bearing material and the tin overlay to act as a diffusion barrier therebetween.
5. A plain bearing according to claim 4 wherein the interlayer is selected from the group comprising: nickel, cobalt, copper, silver, iron and alloys thereof.
6. A method for the deposition of an overlay layer onto the surface of a plain bearing, the bearing comprising a strong backing material having a layer of a first bearing material thereon, said overlay being deposited upon the surface of said first bearing material, the method comprising the steps of: providing a bearing having a surface on which to deposit said overlay; immersing said bearing in a plating solution having a supply of tin ions and an

- organic levelling agent in said solution; making  
said bearing cathodic with respect to an anode in  
said solution; and depositing an overlay of tin,  
apart from unavoidable impurities, said tin overlay  
5 also having said organic levelling agent included in  
a matrix thereof.
7. A method according to claim 6 wherein the overlay is  
deposited in a slot jig apparatus.
8. A method according to claim 7 wherein the plating  
10 solution is sparged through the slot towards the  
bearing bore.
9. A method according to either claim 6 or claim 7  
wherein a plating current density lies in the range  
from 2 to 3 A/dm<sup>2</sup>.
- 15 10. A plain bearing having an overlay layer at a  
sliding surface of the plain bearing substantially  
as hereinbefore described with reference to the  
accompanying description and drawings.
11. A method for the deposition of an overlay layer onto  
20 the surface of a plain bearing substantially as  
hereinbefore described with reference to the  
accompanying description and drawings.

**ABSTRACT**

A plain bearing and method for making the plain bearing are described, the plain bearing having an overlay alloy  
5 layer at a sliding surface of the plain bearing, the plain bearing comprising a layer of a strong backing material, a layer of a first bearing alloy bonded to the strong backing material and a layer of a second bearing material comprising said overlay material bonded to said  
10 first bearing alloy layer wherein said second bearing material comprises tin having included in the matrix thereof an organic levelling agent.

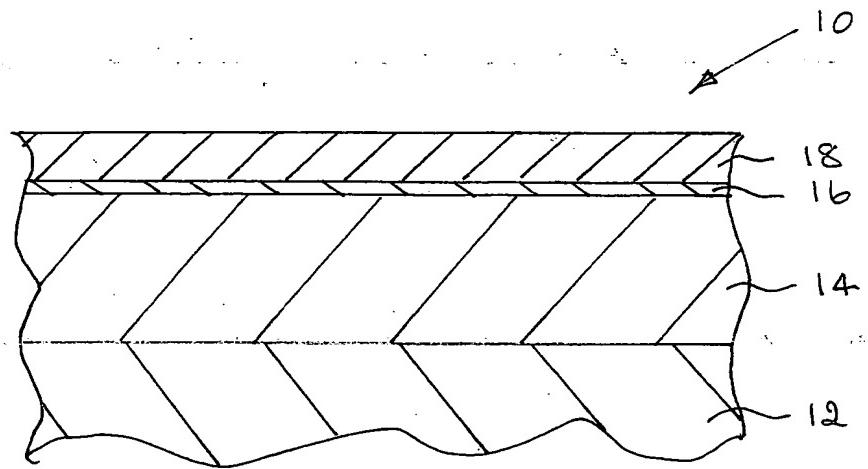


Fig. 1

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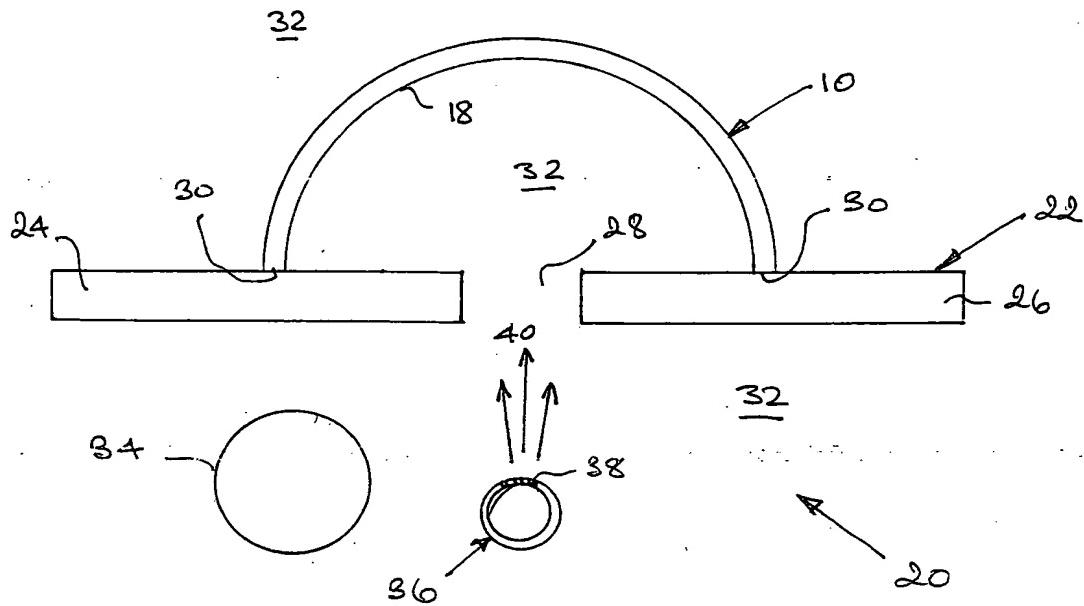


Fig. 2

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**Engine Test**

**Mean Thickness Losses  
From Both Bearings at  
Each Journal after  
3000 hours**

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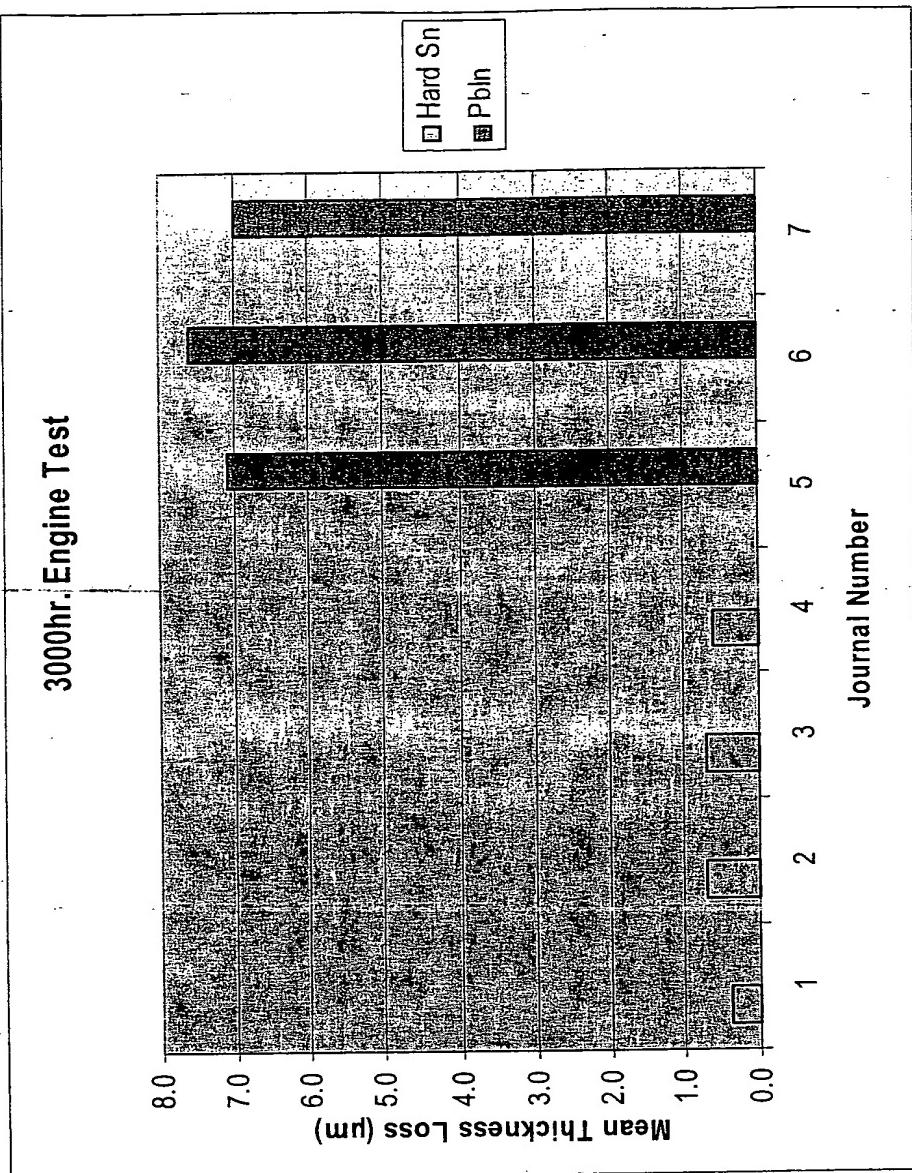
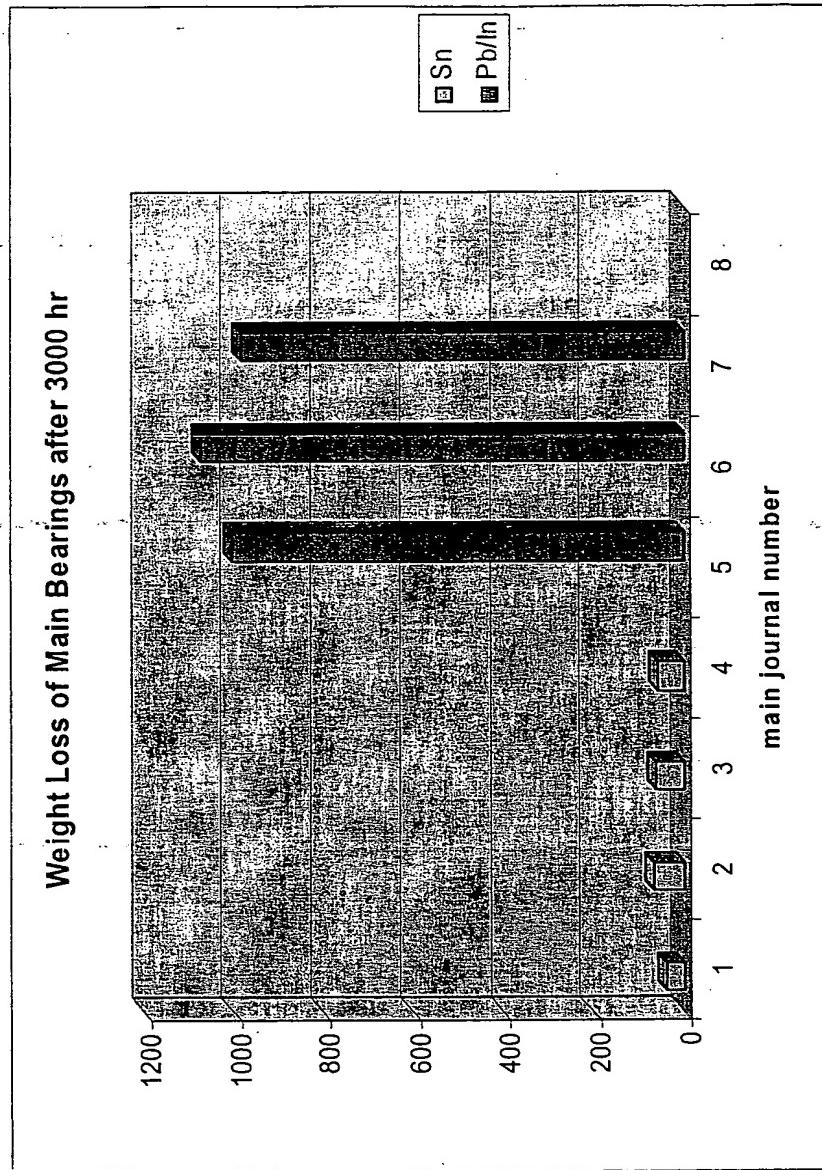


Fig. 3

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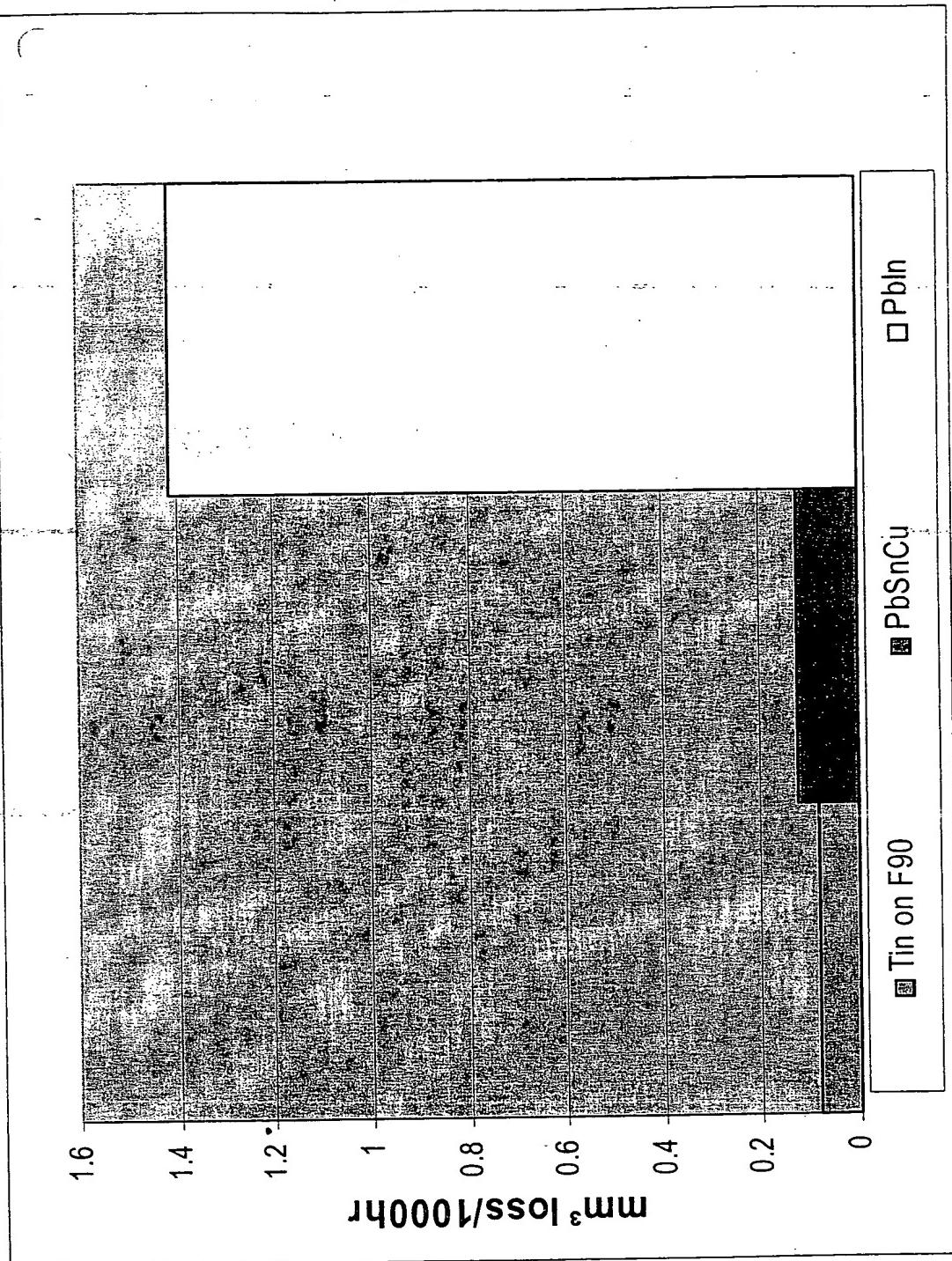
**Engine Test**  
**3000hr**  
**Comparison of wt. Loss**  
**between Sn and PbIn**  
**main bearings**



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Fig 4.

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## Hot Oil Corrosion

Tin on F90 vs.  
two standard  
lead-based  
systems

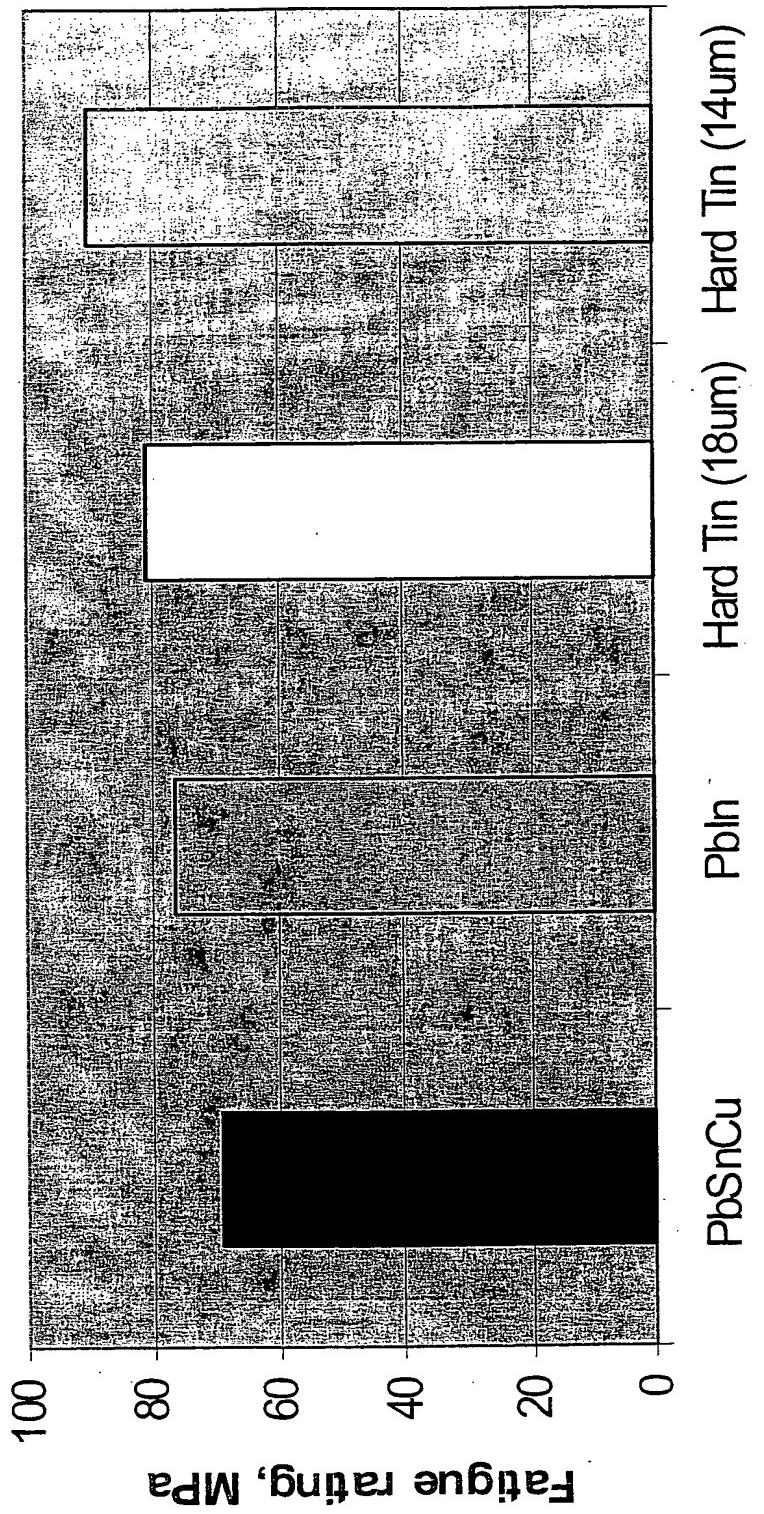
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Fig. 5

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## Sapphire fatigue test data

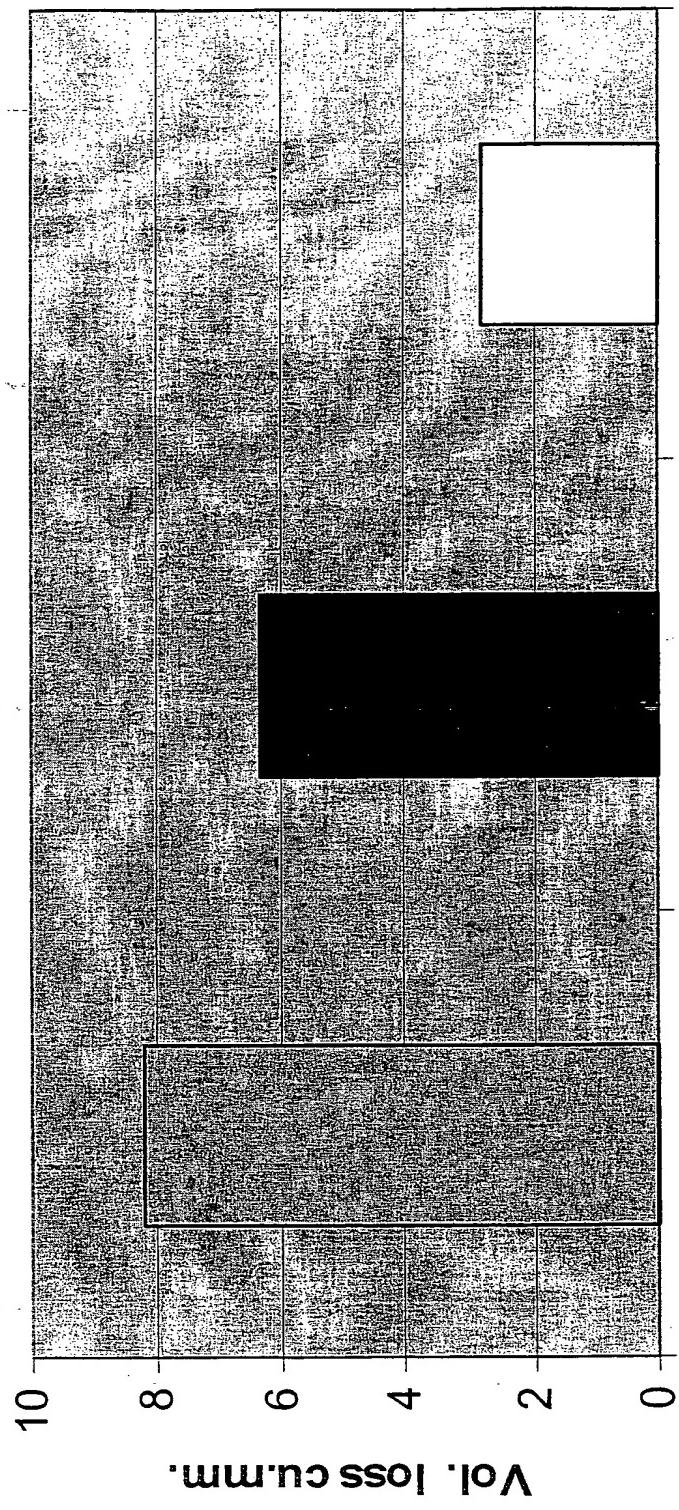


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Fig. 6

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## Wear test data



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Fig. 7

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### Hardness vs. Additions of Leveller

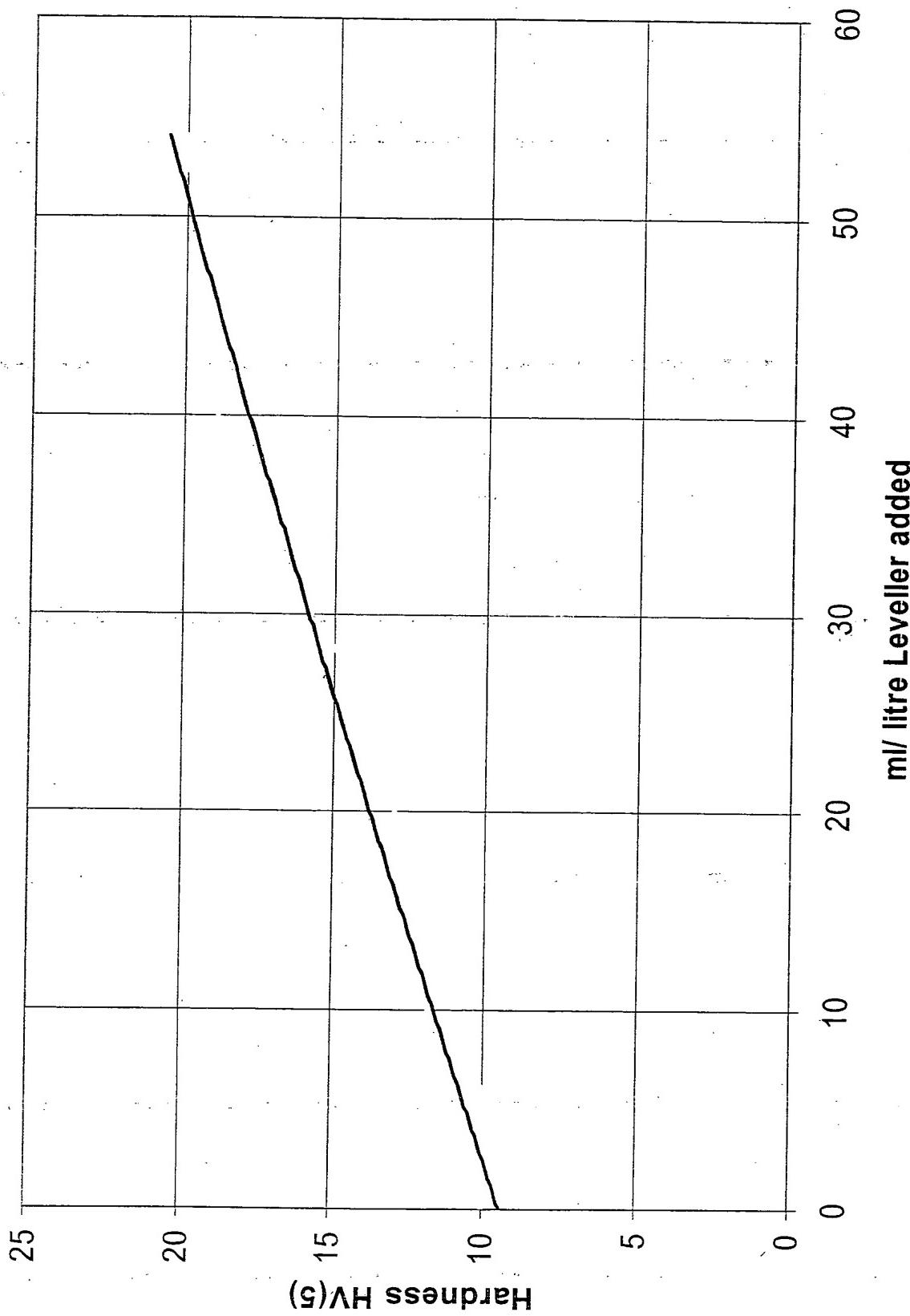


Fig. 8

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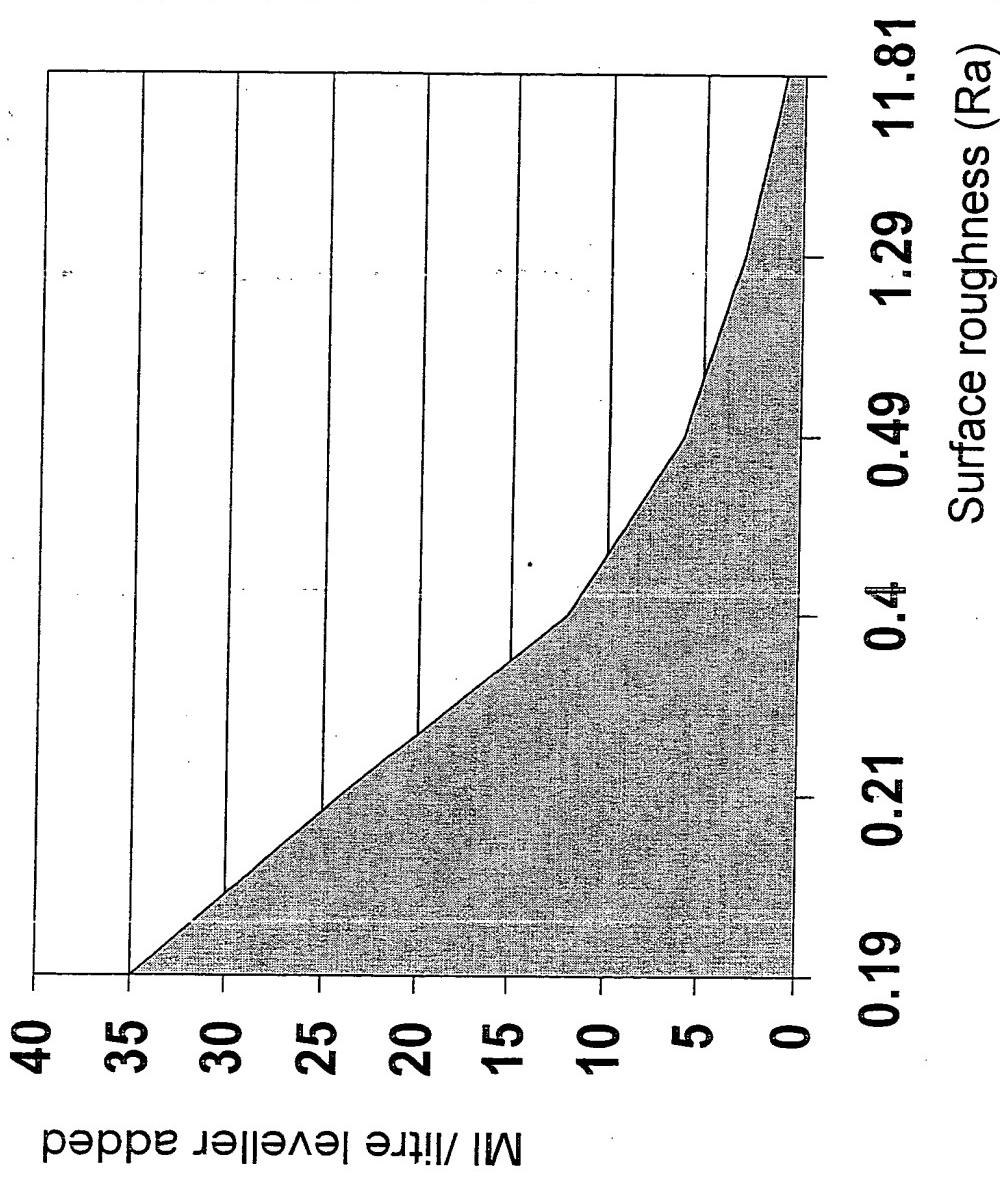


Fig. 9.

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